Circulation in the Vicinity of Descending Overflows

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LONG-TERM GOALS

The long-term goal of this project is to contribute to our understanding of the circulation, exchange, and environment between marginal seas and the open ocean.

OBJECTIVES

To better understand the mean and time-dependent circulations induced in the upper ocean by turbulent entrainment in the vicinity of steep bottom topography.

APPROACH

Idealized numerical modeling studies are used in conjunction with theory to understand the large-scale circulations that are forced by entrainment into spatially variable mixing regions. The results are interpreted and understood by making use of potential vorticity budgets, integral constraints, and thermodynamic balances. Geometries under study include: entrainment in the open ocean, entrainment near steep topography, and entrainment near ridges and seamounts.

WORK COMPLETED

An isopycnal model has been applied to the study of the large scale circulation induced by localized diapycnal mixing in simply and multiply connected domains. Analytic boundary layer solutions have been developed to quantify the dissipation resulting from mixing near boundaries. Fundamental integral constraints have been developed to interpret the resulting circulation patterns and transports as a function of the mixing and topographic parameters.

A nonlinear analytic two-layer model has been developed to study the circulation forced by spatially variable diapycnal mixing over a sloping bottom. Two non-dimensional numbers control the strength of the horizontal circulation and the importance of the nonlinear terms. A series of idealized calculations and an application to the circulation in the deep Brazil Basin have been completed.

RESULTS

The strong, large-scale horizontal recirculation that is forced by open ocean diapycnal mixing is gradually replaced by a weak, unidirectional flow into or out of the mixing region as the mixing is confined near a horizontal boundary. The viscous potential vorticity flux into the boundary replaces the strong horizontal recirculation gyre in the potential vorticity budget. However, if this mixing is along the western side of an island or mid-ocean ridge, the dissipation within the mixing region requires that a strong, large-scale horizontal circulation flow around the topography, connecting the adjacent basins and sometimes extending far from the region of mixing (Figs. 1 and 2). Diapycnal mixing in the open ocean to the east of an island or ridge also requires a horizontal circulation around the topography to the west.

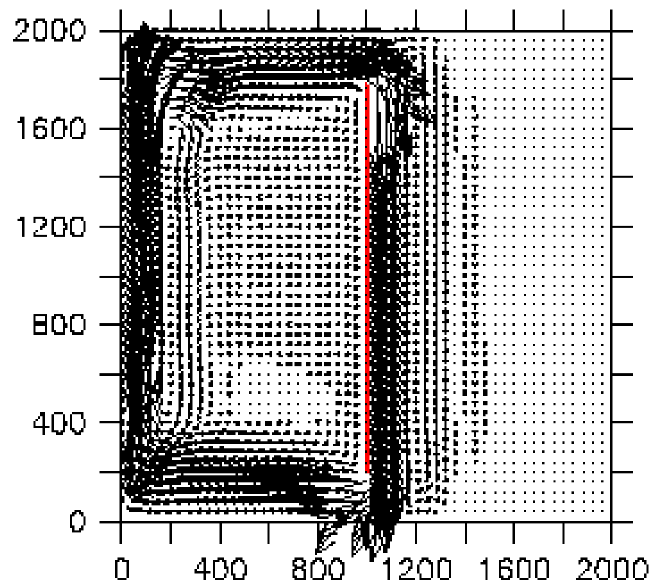

Figure 1: Circulation in the upper ocean forced by diapycnal mixing along the west coast of a narrow island (indicated by the red line). The upwelled mass flows weakly towards the west of the island, but induces a much stronger anticyclonic circulation around the island.

Diapycnal mixing over a sloping bottom results in a weak, unidirectional flow into or out of the mixing region in the deep ocean, and a strong horizontal recirculation in the upper ocean. In this inviscid case, the deep recirculation is exactly eliminated by the interaction of the deep flow with the bottom topography, even when the flow is nonlinear. Application of this analytic model to the deep Brazil Basin produces horizontal and vertical circulations that are in good agreement with recent observations.

IMPACT/APPLICATIONS

These results indicate that mixing near topography can force strong circulations far from the region of mixing. The exchange between marginal seas and the open ocean will be strongly dependent on whether the marginal sea is connected to the open ocean by one strait (e.g., the Mediterranean Sea) or by two or more straits (e.g., the Sea of Japan). Spatially variable mixing over even a very weakly sloping bottom results in a fundamentally different horizontal circulation than does mixing over a flat bottom.

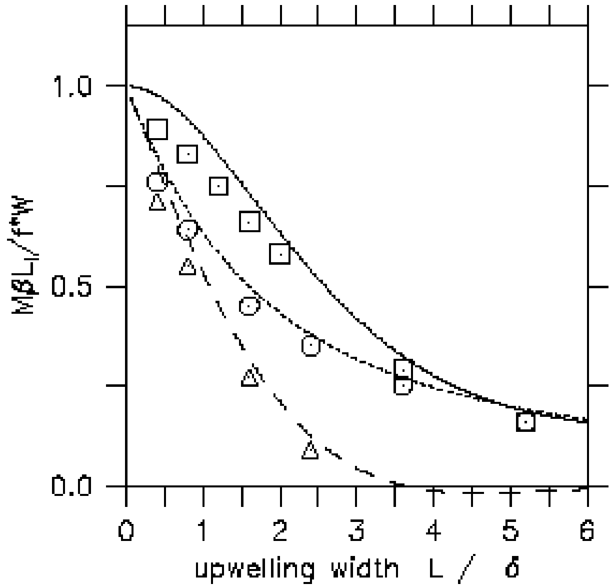

Figure 2: Nondimensional strength of the circulation around an island (M) as a function of upwelling width along the west coast of the island (L). The total amount of upwelled water is W, β is the meridional gradient of planetary vorticity, L_I is the meridional scale of the island, and f* is the Coriolis parameter at the latitude of upwelling. The upwelling width L is nondimensionalized by the viscous boundary layer width δ. Symbols indicate the circulation found in a primitive equation model, lines indicate the circulation predicted by theory. Solid line and squares: lateral viscosity with no-slip boundary conditions. Long dashed line and triangles: lateral viscosity with free-slip boundary conditions. Short dashed line and circles: linear bottom drag. The results indicate that if mixing is confined to a narrow region along the western side of an island or mid-ocean ridge, then a circulation will be forced around the topography that can be much larger than the amount of upwelled water, especially as the meridional scale of the topography becomes small ($M = W f^*/ \beta L_I$).

PUBLICATIONS

Spall, M. A. and R. S. Pickart, 2000. Where does dense water sink? A subpolar gyre example. *J. Phys. Oceanogr.*, in press.

Spall, M. A., 2000. Buoyancy forced circulation around islands and ridges. *J. Marine Res.*, in press.

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